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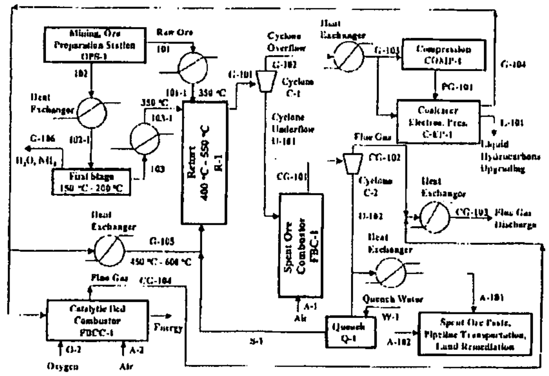
(54) DISTILLATION A LA CORNUE DE PYROSCHISTE, DE SABLES BITUMINEUX, DE CHARBON ET DE SOLS RENFERMANT DES HYDROCARBURES A L'AIDE DE VAPEUR SERVANT DE CALOPORTEUR DANS REACTEUR A LIT FLUIDISE

(54) RETORT OF OIL SHALE, OIL SANDS BITUMEN, COAL AND HYDROCARBON CONTAINING SOILS USING STEAM AS HEAT CARRIER IN FLUIDIZED BED REACTORS

(57)
A fluidized bed retort process is invented for retorting hydrocarbon containing materials such as oil shale, tar sands, coal and hydrocarbon containing soils. having particle diameter of about 7 mm and smaller. A mixture of steam, off-gas and carbon dioxide is used as the heat source and the fluidizing lift gas, and recycled in the process. Hot steam, off-gas and carbon dioxide mixture rapidly increases the temperature of raw particles in the fluidized bed retort, liberates the hydrocarbons with minimal uncontrolled thermal cracking reactions. which increases the recovery efficiency and quality of condensable hydrocarbons. The effluent of the fluidized bed retort, which is composed of steam, off-gas, carbon dioxide, liberated hydrocarbons and solid particles, is dedusted using a cyclone. The cyclone overflow is cooled using a series of heat exchangers, compressed if needed to increase the condensable hydrocarbons yield. The condensed hydrocarbons are separated by using a coalescer followed by an electrostatic precipitator, and, the mixture of steam, off-gas and carbon dioxide is heated using a series of heat exchangers and recycled to the retort as the heat source and fluidizing lift gas. The condensed hydrocarbons are upgraded to synthetic crude oil or marketable products using fractionation. catalytic hydrotreating, catalytic hydrocracking, two step non-catalytic and/or catalytic hydrotreating or coking followed by catalytic hydrogenation processes. A fraction of the steam, off-gas and carbon dioxide mixture is fed to a catalytic fixed bed combustor, at elevated pressures if the cyclone overflow is compressed, to generate heat by combusting its off-gas content using air or pure oxygen as the oxidant. The cyclone underflow, which is the spent ore containing coke and residual hydrocarbons, is fed to a fluidized bed combustor to generate heat by combusting its carbon content using air as the oxidant. The latent heats of the hot combusted spent ore and combustion flue gas generated by the combustion of the spent ore are recovered using a series of heat exchangers and using quench water. Cooled combusted spent ore is

transported in the form of a paste, using a pipe-line [2]transportation system, back to[2]the mine site for land reclamation.[2]



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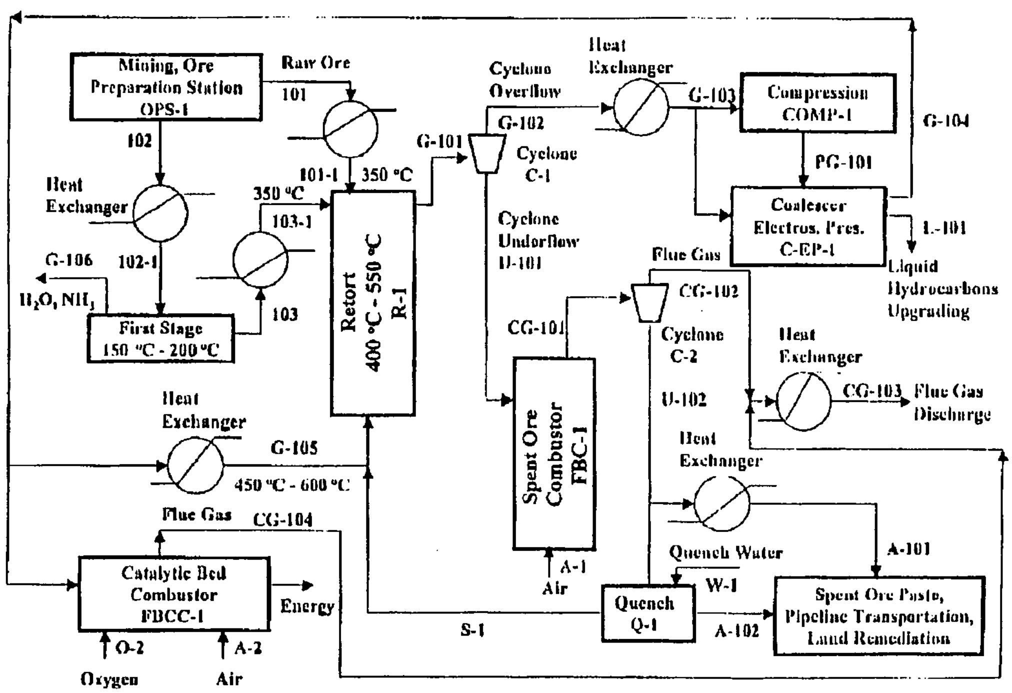


(57) Abrégé/Abstract:
A fluidized bed retort process is invented for retorting hydrocarbon containing materials such as oil shale, tar sands, coal and hydrocarbon containing soils. having particle diameter of about 7 mm and smaller. A mixture of steam, off-gas and carbon

(57) Abrégé(suite)/Abstract(continued):
dioxide is used as the heat source and the fluidizing lift gas, and recycled in the process. Hot steam, off-gas and carbon dioxide mixture rapidly increases the temperature of raw particles in the fluidized bed retort, liberates the hydrocarbons with minimal uncontrolled thermal cracking reactions. which increases the recovery efficiency and quality of condensable hydrocarbons. The effluent of the fluidized bed retort, which is composed of steam, off-gas, carbon dioxide, liberated hydrocarbons and solid particles, is dedusted using a cyclone. The cyclone overflow is cooled using a series of heat exchangers, compressed if needed to increase the condensable hydrocarbons yield. The condensed hydrocarbons are separated by using a coalescer followed by an electrostatic precipitator, and, the mixture of steam, off-gas and carbon dioxide is heated using a series of heat exchangers and recycled to the retort as the heat source and fluidizing lift gas. The condensed hydrocarbons are upgraded to synthetic crude oil or marketable products using fractionation. catalytic hydrotreating, catalytic hydrocracking, two step non-catalytic and/or catalytic hydrotreating or coking followed by catalytic hydrogenation processes. A fraction of the steam, off-gas and carbon dioxide mixture is fed to a catalytic fixed bed combustor, at elevated pressures if the cyclone overflow is compressed, to generate heat by combusting its off-gas content using air or pure oxygen as the oxidant. The cyclone underflow, which is the spent ore containing coke and residual hydrocarbons, is fed to a fluidized bed combustor to generate heat by combusting its carbon content using air as the oxidant. The latent heats of the hot combusted spent ore and combustion flue gas generated by the combustion of the spent ore are recovered using a series of heat exchangers and using quench water. Cooled combusted spent ore is transported in the form of a paste, using a pipe-line transportation system, back to the mine site for land reclamation.

Prescott H. Rathborne

# Retort of Oil Shale, Oil Sands Bitumen, Coal and Hydrocarbon Containing Soils Using Steam as Heat Carrier in Fluidized Bed Reactors

## Abstract

A fluidized bed retort process is invented for retorting hydrocarbon containing materials such as oil shale, tar sands, coal and hydrocarbon containing soils, having particle diameter of about 7 mm and smaller. A mixture of steam, off-gas and carbon dioxide is used as the heat source and the fluidizing lift gas, and recycled in the process. Hot steam, off-gas and carbon dioxide mixture rapidly increases the temperature of raw particles in the fluidized bed retort, liberates the hydrocarbons with minimal uncontrolled thermal cracking reactions, which increases the recovery efficiency and quality of condensable hydrocarbons. The effluent of the fluidized bed retort, which is composed of steam, off-gas, carbon dioxide, liberated hydrocarbons and solid particles, is dedusted using a cyclone. The cyclone overflow is cooled using a series of heat exchangers, compressed if needed to increase the condensable hydrocarbons yield. The condensed hydrocarbons are separated by using a coalescer followed by an electrostatic precipitator, and, the mixture of steam, off-gas and carbon dioxide is heated using a series of heat exchangers and recycled to the retort as the heat source and fluidizing lift gas. The condensed hydrocarbons are upgraded to synthetic crude oil or marketable products using fractionation, catalytic hydrotreating, catalytic hydrocracking, two step non-catalytic and/or catalytic hydrotreating or coking followed by catalytic hydrogenation processes. A fraction of the steam, off-gas and carbon dioxide mixture is fed to a catalytic fixed bed combustor, at elevated pressures if the cyclone overflow is compressed, to generate heat by combusting its off-gas content using air or pure oxygen as the oxidant. The cyclone underflow, which is the spent ore containing coke and residual hydrocarbons, is fed to a fluidized bed combustor to generate heat by combusting its carbon content using air as the oxidant. The latent heats of the hot combusted spent ore and combustion flue gas generated by the combustion of the spent ore are recovered using a series of heat exchangers and using quench water. Cooled combusted spent ore is transported in the form of a paste, using a pipe-line transportation system, back to the mine site for land reclamation.

## Description

FIELD OF INVENTION

This invention relates to a process for retorting oil shale, oil sands, coal and hydrocarbon containing soils using a fluidized bed retort using the mixture of steam, off-gas and carbon dioxide as the heat source and the fluidizing lift gas.

**Prescott H. Rathborne**

BACKGROUND OF THE INVENTION

Economically viable and environmentally acceptable methods for the recovery of hydrocarbons from oil shale, oil sands, coal and hydrocarbon containing soils have been under investigation for many years. Research efforts have been focused on recovering liquid hydrocarbons from oil shale, oil sands and coal for the production of transportation fuels such as gasoline, diesel and jet fuel. Direct coal liquefaction was commercially used in Germany to produce aviation fuel during the World War II. Indirect coal liquefaction, such as coal gasification followed by catalytic hydrogenation of carbon monoxide to hydrocarbons, is already commercialized.

Since late 1960s, production of synthetic crude oil from the oil sands bitumen became commercial. In Alberta, Canada, there are two commercial plants producing synthetic crude oil from Athabasca oil sands. Caustic hot water extraction process, which is known as the Clark hot water process, is used for the extraction of bitumen from the Athabasca tar sands. Extraction efficiency of the Clark's hot water process is as high as 90 % to 92 % by weight, for the tar sands containing about 10 % to 12 % by weight hydrocarbons. After the bitumen extraction process, bitumen is coked by a thermal process to produce coker gas oil. The coking process is also called the primary upgrading, which yields about 70 % by weight liquid hydrocarbons and 15 % to 20 % by weight petroleum coke. During thermal coking process, asphaltenes or coke precursor species present in bitumen are converted to coke, liquid and gaseous hydrocarbons. Delayed and fluid cokers are used for the thermal coking of bitumen to produce coker gas oil. The coker gas oil is hydrogenated to produce synthetic crude oil, which is also known as the secondary upgrading, by using catalytic hydrogenation process operating at about 370 °C to 430 °C temperature and pressures of about 10 MPa to 25 MPa pressure. The primary and secondary upgrading processes convert bitumen from about 8 °API to 10 °API gravity and atomic hydrogen to carbon ratio of about 1.5 into synthetic crude oil of about 35 °API gravity and atomic hydrogen to carbon ratio of about 1.8. Also, a catalytic hydrocracking process, such as LC-Finer process, can replace the coking followed by catalytic hydrotreating processes, or, integrated to the coking followed by catalytic hydrotreating processes as it has been used by Suncrude Canada Ltd. since 1988.

Production of synthetic crude oil from oil sands bitumen has two shortcomings, both of which are related to the hot water extraction process. The first shortcoming is that it needs a large volume of water, in the order of about 9 volumes of water per volume of synthetic crude oil produced. The second shortcoming, which remains as an environmental problem, is that hot water extraction process produces a tailings effluent stream. Sands particles precipitate rapidly upon the disposition of the tailings, while the fine clay particles are carried by water into the sedimentation lagoons, from which over the years the mature fine tailings is formed containing about 35 % by weight of solids. The solid content of the mature fine tailings is basically fine tails, which may remain in a fluid state for centuries because of their very slow consolidation rate.

Hot water bitumen extraction process and conversion of bitumen into coker gas oil by coking process can be combined in a single step process, which is the retort process, if a retort process can be economically operated in commercial scale. Such a retort process could eliminate the requirement of large volume of water for the extraction process and the formation of mature fine

tailings problem. In other words, a suitable one step retort process could replace the hot water extraction and coking processes. Implementation of such a one step retort process could significantly reduce the cost of synthetic crude oil production and could eliminate the environmental problems associated with the tailings effluent of the hot water extraction process.

Like oil sands bitumen, oil shale deposits could also be developed for the commercial production of synthetic crude oil, economically. Vast deposits of oil shale are found in the United States, Western Canada, Australia, Russia, Brazil, Estonia, China and Middle East. Oil shale is basically a fine-grained sedimentary rock containing organic matter known as "kerogen" which has limited solubility in common solvents and therefore can not be recovered by the extraction processes. Upon heating however, kerogen decomposes by pyrolysis, thermal cracking or distillation to yield oil, gas, dust and residual carbon. It has been estimated that an equivalent of 7 trillion barrels of oil are contained in oil shale deposits in the United Sates with more than half of those located in the Green River oil shale deposits of Colorado, Utah and Wyoming. Using existing retort processes, a medium grade Colorado oil shale may yield about up to 25 gallons oil per ton of ore and a specific grade of Saskatchewan oil shale may yield about up to 14 gallons of oil per ton of shale.

Most oil shale ore deposits contain carbonate minerals such as dolomite and calcite, concentrations of up to 35 % by weight. Decomposition of these carbonate minerals during the retort of oil shale may consume considerable amount of heat, in some cases up to 5 % to 10 % of the whole thermal energy injected into the retort, eventually reduces the energy efficiency of the retort process. Decomposition of the carbonate minerals can be suppressed by operating the retort at the lowest temperature possible, and, allowing the presence of sufficient amount of carbon dioxide in the recycle gas. The recycle gas is the mixture of steam, off-gas and carbon dioxide, which is introduced to the fluidized bed retort as the heat source and the fluidizing lift gas.

In general, shale oils produced from oil shale ores using the existing retort processes are of low yield and of relatively poor quality. Operating conditions such as ore particle size, hydrodynamic conditions in the retort and gas phase composition contacting the shale particles in the retort determines the oil yield and oil quality. Retort operating conditions control the mass and heat transfer between the particles and their surrounding environments, particle heating rate, contact time between the ore and the liberated hydrocarbons and suppression of the unwanted pyrolysis, thermal cracking or decomposition reactions. All of these are the parameters effecting the oil yield and oil quality of the retort process. As a result, retort design and retort operating conditions are the key factors for the performance of the retort process.

## SUMMARY OF THE INVENTION

A fluidized bed retort process and system is invented for retorting hydrocarbon containing materials such as oil shale, tar sands, coal and hydrocarbon containing soils. The retort process operates for the raw ore particles smaller than 7 mm in diameter. A mixture of steam and off-gas is used as the heat source and the fluidizing lift gas, and recycled in the process. Water is supplied into the system to compensate its loses in the system, most preferably in the form of steam generated from the quench water.

The retort process described in this invention could also be operated, if needed, as of a two stage retort process. The first stage of the retort process, which is a fixed bed or a fluidized bed preheating or pretreatment system, operating in any fluidization mode, of which the operating temperature is kept in the range of 150 °C to 200 °C. In the first stage of the retort process, the raw ore would lose its moisture water and other recoverable chemical species such as ammonia if the raw ore contains ammonium sulfate, and, the recovered chemical specie such as ammonia is recovered from the gas effluent stream of the first stage. After treating the raw ore in the first stage, ore particles are further heated up to about 350 °C by using a series of heat exchangers and transferred in to the second retort stage, which is also called the retort stage. The retort stage, which is a fluidized bed retort operating in the spouted, bubbling, entrained or circulating bed modes. In this stage the temperature is kept in the range of 400 °C to 550 °C, depending on the overall process objectives, for the liberation of the hydrocarbons from the raw ore.

The exit stream of the retort is dedusted using a cyclone. The cyclone overflow, which is a mixture of steam, off-gas, carbon dioxide and liberated hydrocarbons, cooled for the condensation of the liberated hydrocarbons. This process can be made at elevated pressures, up to 4 MPa. to increase the yield of condensed hydrocarbons. After the cooling, the mixture is fed to a coalescer and an electrostatic precipitator for the precipitation of liquid hydrocarbons. The gaseous hydrocarbons, which could not be condensed in this process, is called the off-gas. The gas mixture, which is composed of steam, carbon dioxide and off-gas, is heated up to 450 °C to 600 °C temperature, and, recycled back to the retort process as the heat source and the fluidizing lift gas. The recycled mixture of steam, carbon dioxide and off-gas contains sufficient amount of carbon dioxide, which is generated during the retort of the raw ore. Presence of carbon dioxide in the recycle gas suppresses the decomposition of dolomite and calcite content of the raw ore during the retort process. Also, a fraction of the mixture of steam, carbon dioxide and off-gas is combusted, if needed, using a catalytic bed combustor operating at atmospheric or elevated pressures up to 4 MPa for the generation of thermal energy and using oxygen or air as oxidants. Also, the carbon deposited in the spent ore in the cyclone underflow stream is combusted using a fluidized bed combustor for thermal energy generation using air as oxidant.

Liquid hydrocarbons, which are liberated from the raw ore in the retort process, then cooled and condensed and are upgraded to produce synthetic crude oil or any marketable hydrocarbon products. There are many upgrading process options for the upgrading of the hydrocarbons. Fractionation, catalytic hydrotreating, catalytic hydrocracking, two step non-catalytic and/or catalytic hydrotreating or coking followed by catalytic hydrotreating processes could be used for this purpose.

After combusting the coke or residual hydrocarbon deposited on the spent ore, hot spent ore is cooled by using a series of heat exchangers or using quench water. The steam generated from the quench water is the back-up water for the process, since the steam generated by injecting the quench water to cool down the hot spend ore is used in the retort process. After cooling, the spent ore is transported back to the mine site, in the form of a paste by the addition of water, using a pipe-line transportation system. With the paste technology, land reclamation could take less than one year, while it may take possibly centuries in other systems.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic process flow diagram of a retorting system equipped with a fluidized bed retort in accordance with principles of the present invention.

DESCRIPTION OF THE PREFERED EMBODIMENT

A novel retorting process system as depicted in Figure 1, equipped with a fluidized bed reactor is invented to retort hydrocarbon containing materials such as oil shale, tar sands, coal and hydrocarbon containing soils.

Raw ore, which is the term used to define oil shale, tar sands, coal or hydrocarbon containing soils, and, blend of any of these. Ore is mined, crushed and screened to smaller than 7 mm in diameter in the mining and ore preparation station OPS-1 and is fed to a series of heat exchangers by the ore feed stream line 101. In these heat exchangers ore particles are heated from ambient temperature to about 350 °C temperature by recovering the latent heat of the spent ore discharged from the spent ore combustor and fed to the retort by the feed line 101-1.

If a two stage retort is needed, the screened ore with smaller than 7 mm in diameter in the raw ore feed stream line 102 is fed to a series of heat exchangers and to the first stage of the retort. This stage is also defined as the pretreatment stage, operating temperature of which is kept in the range of 150 °C to 200 °C. In the first stage of the retort process the raw ore particles lose the moisture water and other chemical species which might be liberated as a result of the mild thermal treatment. As an example, if the raw ore contains ammonium sulfate, thermal decomposition of ammonium sulfate to ammonia and ammonium hydrosulfate, which takes place at about 100 °C, is achieved in the first step of the retort. Ammonia in the gas line G-106 is recovered from the gas effluent of the first step of the retort, while ammonium hydrosulfate is chemically stable, stays in the solid phase and carried over to the fluidized bed retort together with the dried raw ore. After the pretreatment in the first stage, ore in line 103 is fed to a series of heat exchangers, and, hot ore at about 350 °C temperature in line 103-1 is fed to the retort.

Injection of the heated ore into the retort R-1 is maintained at a solid flux flow rate of 20 t/m.sup.2 hr to 500 t/m.sup.2 hr, which is operating in the spouted, bubbling, entrained or circulating bed modes. A mixture of steam, off-gas and carbon dioxide in line G-105, at about 450 °C to 600 °C temperature range, is injected into the fluidized bed retort through a specifically designed nuzzle orientations at the conical section and at the bottom section of the fluidized bed retort. The feed gas, which is a mixture of steam, off-gas and carbon dioxide, is the heat source and the fluidizing lift gas, which is partially recycled in the process.

In the fluidized bed retort, ore particles of smaller than 7 mm in diameter are in continuous motion and contacting to each other by collisions and they are in good contact with the hot fluidizing gas. Hydrodynamic conditions in the fluidized bed retort promote mass and heat transfer between the hot fluidizing gas and ore particles as well as between the ore particles. These hydrodynamic conditions provide fast heating rate for the particles, uniform temperature in the retort and fast transfer of

liberated hydrocarbons from solid ore particles to the gas atmosphere surrounding the ore particles. During the retort, part of the elemental oxygen present in the hydrocarbon structure of the raw ore is also liberated, most probably as carbon dioxide.

Density of the ore particles in the retort decreases as the retort process progresses. Density of the spent ore becomes small enough at an acceptable hydrocarbon liberation level and spent ore particles leave the retort by entraining in the fluidizing gas stream. Also, diameters of the spent ore particles get smaller as a result of extensive particle-particle collisions in the retort. Small size spent ore particles leaves the retort by entraining in the fluidizing gas also.

The exit stream of the retort in line G-101, which is composed of steam, off-gas, carbon dioxide, hydrocarbons and spent ore particles, is fed to a cyclone C-1 for dedusting. Cyclone underflow stream of U-101, which is the spent ore, is fed to a fluidized bed combustor FBC-1 for heat generation by combusting its coke and residual hydrocarbon. Hot air in line A-1 is injected into the bottom of the fluidized bed combustor and temperature of the fluidized bed combustor is maintained at about 600 °C - 900 °C. Lower operating conditions in the fluidized bed combustor is desired to suppress the decomposition of calcium and magnesium sulfates, which are formed in the combustor as a result of chemical reactions between the trioxide, and, dolomite and calcite minerals of the raw ore. Sulfur trioxide is the oxidation product of the sulfur of the coke and the residual hydrocarbons, which is formed in the oxidative atmosphere of the combustion process. However, operating temperature of the spent ore combustor is very much depended on the combustion reactivity of the coke or residual hydrocarbon on the spent ore pore spaces. Flue gas coming out from the combustor in line CG-101 is fed to a cyclone C-2 for dedusting. Cyclone overflow in line CG-102, which is hot flue gas is fed to heat exchangers and discharged into the atmosphere as cooled flue gas in line CG-103.

Cyclone underflow in line U-102, which is the hot combusted spent ore, is fed to heat exchangers and/or cooled by quench water for the recovery of its latent heat. The steam in line S-1, which is generated by injecting quench water in line W-1 on to the hot spent ore in the quench unit Q-1. The steam in line S-1 is fed to the recycled gas and used for the retort process. After the quenching, cooled combusted spent ore in line A-102 is fed to paste making station and transported to the mine site in the form of a paste by a pipeline system and discharged for land reclamation.

Hydrocarbons in the cooled gas in line G-103 are precipitated using a coalescer and an electrostatic precipitator C-EP-1, and the recovered liquid hydrocarbons in L-101 is fed to the upgrading station. If compression is preferred to increase the efficiency of hydrocarbon condensation and recovery, the gas mixture in line G-103 is fed to compression station COMP-1, and compressed gas in PG-101 is fed to C-EP-1 for the precipitation of the condensed hydrocarbons. If the compression of the gas in line G-103 is desired, the coalescer and electrostatic precipitator C-EP-1 are also operated under the pressurized conditions.

A fraction of the cooled recycled gas in line G-104, which is the gas coming out of the coalescer and electrostatic precipitator C-EP-1 is heated up to 450 °C to 600 °C temperature range using a series of heat exchangers. A fraction of the cooled recycled gas in line G-104 is fed to a fixed bed catalytic

combustor FBCC-1 and its off-gas content is combusted, using air in line A-2 or oxygen in line O-2 as oxidant, for heat generation. If the gas in line G-104 is compressed. FBCC-1 unit is also operated under the pressurized conditions. The flue gas effluent of FBCC-1 in line CG-104 is fed to a series of heat exchangers to recover its latent heat. and. discharged to the atmosphere after cooling.

The present invention has the following advantages for the retort of oil shale. oil sands bitumen, coal and hydrocarbon and hydrocarbon containing soils:

1. operates by sealing the penetration of the air and/or oxygen into the retort and hydrocarbon recovery processes, which provides the best operating conditions for achieve high hydrocarbon recovery efficiency and high product quality;

2. provides more trouble free operating conditions;

3. increases raw ore processing capacity;

4. generally uses shelf-ready and conventional processes;

5. reduces the capital cost of synthetic crude oil production from non-conventional hydrocarbon resources;

6. reduces operating cost of synthetic crude oil production from non-conventional hydrocarbon resources; and,

7. eliminates or reduces the major environmental problems associated with the synthetic crude oil production from non-conventional hydrocarbon resources.

Although embodiments of this invention have been described and shown, it is to be understood that various changes, modifications and substitutions, as well as rearrangements of parts and combination of process steps thereof may be made without departing from the novel spirit and the scope of this invention.

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## Claims

1. A process for retorting hydrocarbon containing raw materials such as oil shale, tar sands, coal and hydrocarbon containing soils, comprising the steps of:

(a) introducing the raw materials such as oil shale, tar sands, coal or hydrocarbon containing soils, or, blend of any of the above defined raw materials, having particle diameter of about 7 mm and smaller, into the fluidized bed retort;

(b) introducing the mixture of steam, off-gas and carbon dioxide into the fluidized bed retort as the heat source and the fluidizing lift gas, and partially recycling the mixture of steam, off-gas and carbon dioxide in the process;

(c) contacting the particles of raw material with hot mixture of steam, off-gas and carbon dioxide in the fluidized bed retort, which is operating in the spouted, bubbling, entrained or circulating bed modes, increasing mass and heat transfer rates between the hot gas and raw particles and increasing the heat transfer rates between the particles accomplishing a rapid heating of the raw particles to rapidly liberate their hydrocarbon contents with minimum unwanted thermal cracking reactions and maintaining a uniform temperature in the retort;

(d) dedusting the effluent of the fluidized bed retort, which is composed of steam, off-gas, carbon dioxide, liberated hydrocarbons and dust, by using a cyclone;

(e) cooling the cyclone overflow, which is composed of steam, off-gas, carbon dioxide and liberated hydrocarbons, by using a series of heat exchangers and condensing the liberated hydrocarbons;

(f) separating the condensed hydrocarbons form the cooled cyclone overflow effluent, by using a coalescer and an electrostatic precipitator;

(g) upgrading the condensed hydrocarbons to synthetic crude oil or marketable products using fractionation, catalytic hydrotreating, catalytic hydrocracking, two step non-catalytic and/or catalytic hydrotreating or coking followed by catalytic hydrotreating processes;

(h) recycling the mixture of steam, off-gas and carbon dioxide after the electrostatic precipitator, by heating the mixture of steam, off-gas and carbon dioxide to desired temperature range, by using a series of heat exchangers;

(i) combusting the carbon content of the cyclone underflow, which is the used ore of the retort process containing coke and/or residual hydrocarbons, using a fluidized bed combustor to generate heat and using air as the oxidant;

(j) dedusting the effluent of the fluidized bed combustion process, which is the flue gas of the process of claim 1-(i), using a cyclone;

(k) cooling the cyclone underflow. which is the hot spend ore. and, the cyclone overflow, which is the hot flue gas. both are of the process of claim 1-(j) by using a series of heat exchangers and quench water to recover their latent heats: and.

(l) combusting the off-gas content of the recycle gas. which is the mixture of steam, off-gas and carbon dioxide, after its condensed hydrocarbons are separated using the coalescer and electrostatic precipitator, by feeding a fraction of the recycle gas to a catalytic bed combustor to generate heat and by using oxygen or air as oxidants.

2. The process of claim 1, further comprising of:

(a) the process of claim 1, wherein the retort of raw ore and recovery of liberated hydrocarbons are performed by sealing the process units from penetration of air or oxygen;

(b) the process of claim 1-(e), wherein compressing the recycled mixture of the steam, off-gas, carbon dioxide and hydrocarbons. which is the cooled cyclone overflow effluent, to increase the yield of hydrocarbons condensation;

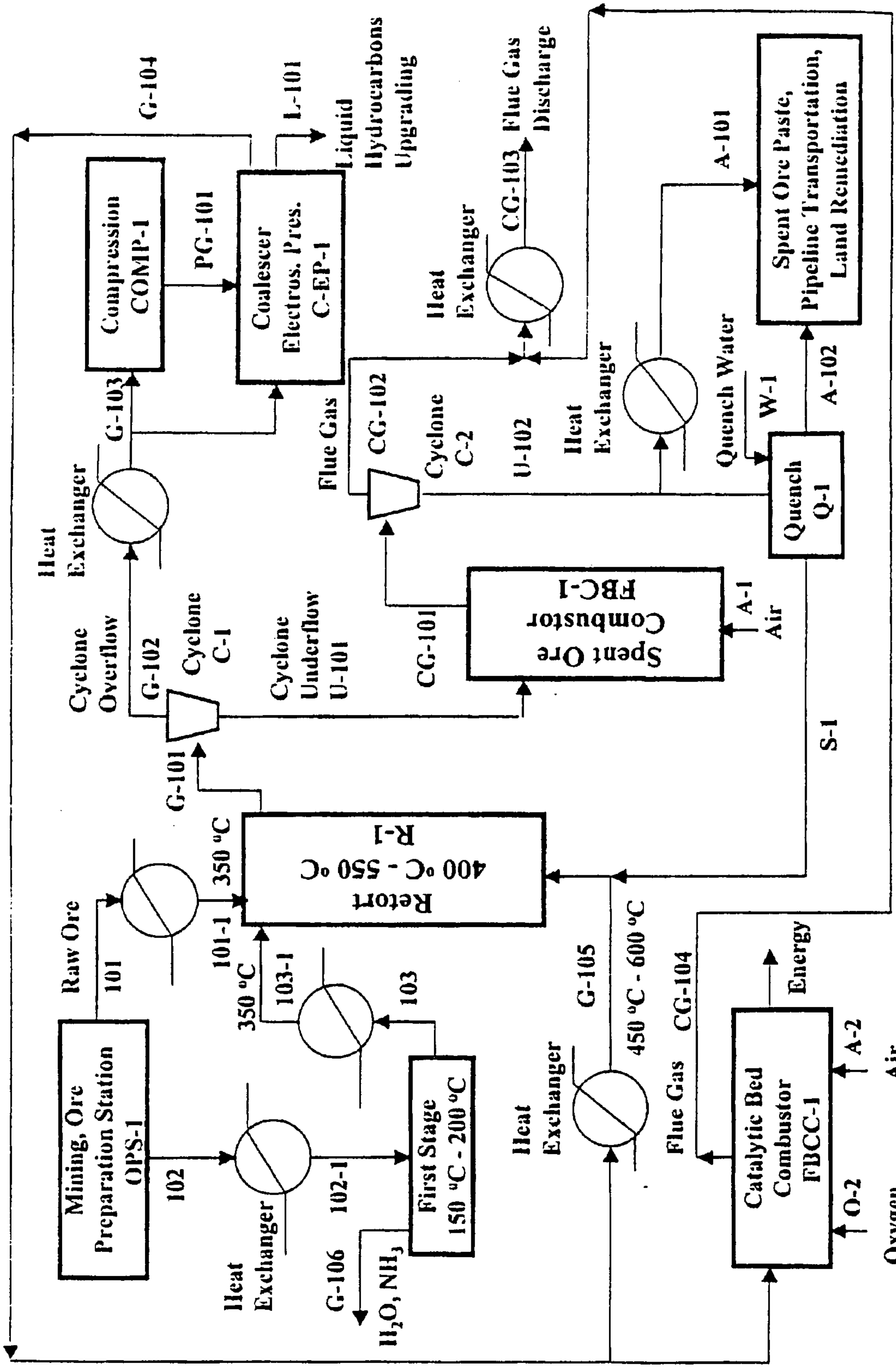
(c) the process of claim 1-(l), wherein combusting the off-gas content of the recycle gas, which is the mixture of steam, off-gas and carbon dioxide under pressurized conditions after the condensed hydrocarbons are separated using a coalescer an electrostatic precipitator, by feeding the fraction of the recycle gas to a pressurized catalytic bed combustor to generate heat and using oxygen or air as oxidants;

(d) the process of claim 1-(c), wherein the elemental oxygen content of the hydrocarbons contained in the of the raw ore is liberated as carbon dioxide during the retort and accumulated during recycling the gas mixture of steam, off-gas and carbon dioxide;

(e) the process of claim 1-(c), wherein ensuring the recycled gas, which is the mixture of steam, off-gas and carbon dioxide contains sufficient amount of carbon dioxide to inhibit the decomposition of carbonates in the raw ore, which saves energy; and,

(f) injecting make-up water, most preferably in the form of steam generated from the quench water, to the recycled gas mixture of steam, off-gas and carbon dioxide to maintain the steam concentration in the recycled gas at a desired level, as an example, above 50 % by volume, to increase the hydrocarbon yield and quality in the retort process.

Figure 1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Raw Ore
101
102
Heat Exchanger
102-1
First Stage 150 °C - 200 °C
G-106
$H_2O$, $NH_3$
103
103-1
350 °C
101-1
350 °C
Retort 400 °C - 550 °C R-1
G-101
Cyclone Overflow
G-102
Cyclone C-1
Cyclone Underflow U-101
CG-101
Spent Ore Combustor FBC-1
A-1
Air
Heat Exchanger
G-103
Compression COMP-1
PG-101
Coalescer Electros. Pres. C-EP-1
G-104
L-101
Liquid Hydrocarbons Upgrading
Flue Gas
CG-102
Cyclone C-2
U-102
Heat Exchanger
CG-103
Flue Gas Discharge
Heat Exchanger
Quench Water
W-1
Quench Q-1
A-102
A-101
Spent Ore Paste, Pipeline Transportation, Land Remediation
S-1
Heat Exchanger
G-105
450 °C - 600 °C
CG-104
Flue Gas
Catalytic Bed Combustor FBCC-1
Energy
A-2
Air
O-2
Oxygen